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LIQUEFACTION, LATERAL SPREADING, SLOPE AND EMBANKMENT FAILURES DURING THE MARCH 13 EARTHQUAKE OF ERZİNCAN, TURKEY

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ABSTRACT

An earthquake of magnitude 6.8 occured at 19:19 on the local time on March 13, 1992 in Erzincan, which killed more than 590 people and caused heavy damage to more than 17000 buildings. The city is situated on a pull-apart basin on the famous *North Anatolian Fault*. The authors visited the site and observed damage to buildings and geotechnical structures. In this article, the main emphasis put upon the geotechnical structures. In particular, liquefaction and liquefaction induced lateral spreading of ground, failures of soil and rock slopes and of embankments of roadways, canals and roadways are reported and the causes of the above geotechnical problems are discussed on the basis of laboratory and in-situ tests and site explorations.

KEYWORDS

Erzincan; earthquake; liquefaction; lateral spreading; slope; rock; soil; embankment

INTRODUCTION

An earthquake of magnitude 6.8 occured at 19:19 on local time on March 13, 1992 in Erzincan, which was subjected to big earthquakes in the past and situated on the famous *North Anatolian Fault* (NAF). Following the earthquake on March 13, there were numerous aftershocks of intensive ones. The earthquake caused the loss of lives more than 590 and destroyed or heavily damaged buildings totaling more than 17000 and made 35000 people homeless. Landslides, avalanches and snow-slides occured during or soon after the earthquake shook the city of Erzincan and its environment. The authors visited the site and observed damage to buildings and geotechnical structures. In this article, the authors are mainly concerned with geotechnical structures and report on

1) Liquefaction and liquefaction induced lateral spreading of ground,
2) Soil and rock slope failures, and
3) Failures of embankments of roadways, canals and bridges.

Furthermore, the causes of the above geotechnical problems are discussed on the basis of laboratory and in-situ tests and site explorations.

GEOGRAPHY, GEOLOGY AND SEISMICITY

Geography

Erzincan is situated in an ovaloidical basin, which is 50 km long and 15 km wide, in the North-East of Turkey (Fig. 1). It is surrounding by high mountains, namely Mercan Mountains in the north and Munzur Mountains in the south. The altitude of the basin floor ranges between 1000 m to 1200 m and it has a relatively small gradient of 2%. The upstream of Fırat(Euphrates) River, which is the largest river in the Middle East, flows through the basin.

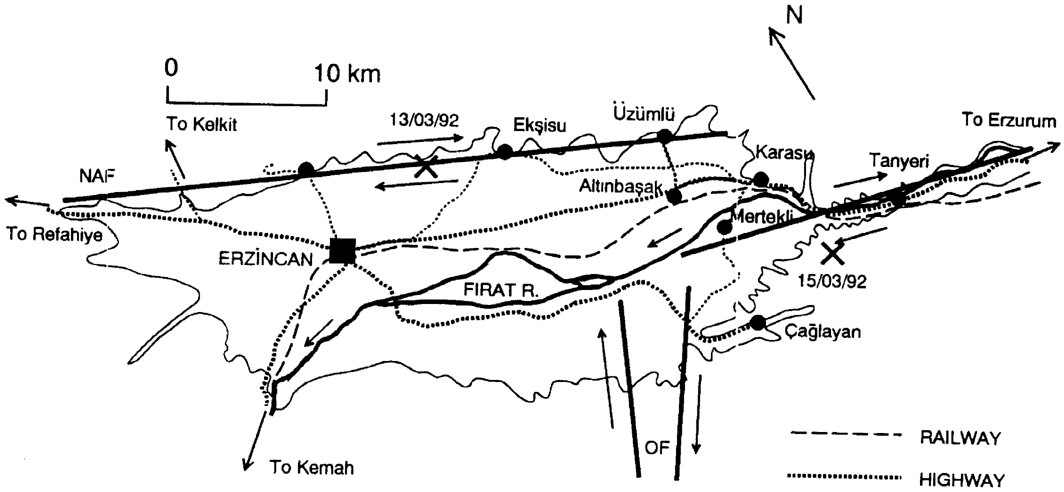

Fig. 1 Geography of the Erzincan Basin

Geology

Although there is not any boring deeper than 250 m for Erzincan Ovası (Basin), the geological information is available from geophysical explorations and shallow borings by Devlet Su İşleri (D.S.İ) (State Hydraulic Works Directorate of the Ministry of Energy and Natural Resources) and outcrop surveying of the region. Fig. 2 shows a stratigraphical column reported by Koçyiğit (1992). From this, it is said that an alluvial sedimentary layer of 300 m thick overlays a layer consisting of conglomerate, volcaniclastics and probably fault brecia. The base and sides of the basin consists of ofiolitic melange overlaid by a limestone formation (Fig. 3). On the northern side of the basin volcanic cones exist which are probably consequences of the creation of tension gashes due to the shear motions of the NAF in the geologic past. Volcanics ranges from rhyolitic series to basaltic series. According to geophysical explorations, the crust beneath the NAF is thinner than that of the both sides of the fault.

According to the borings of D.S.İ, the alluvial deposit consists of alternating layers of clay, silt, sand and gravel. Among all boring data, a boring well L4 at the Northern side of the basin near Üzümlü crosses rock formations. The borings near the northern side of the basin revealed that layers of sand and gravel were very thick and silt and clay layers were thin. On the other hand, the thickness of clay layers increases towards the center of the basin. Beneath the old Erzincan city, which was completely destroyed during the great 1939 earthquake, clay layers are very thick and some clay layers are more than 100 m thick. The formations under the new Erzincan city consists of mostly gravel and sandy layers, intercalated with silty sand layers of 4-10 meters thick, are found near the ground surface.

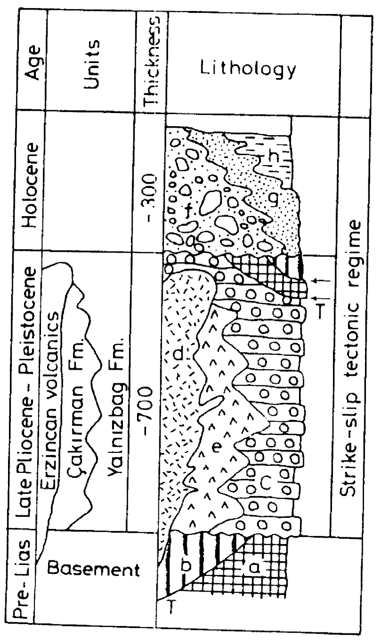

Fig. 2 Tectono-stratigraphical column

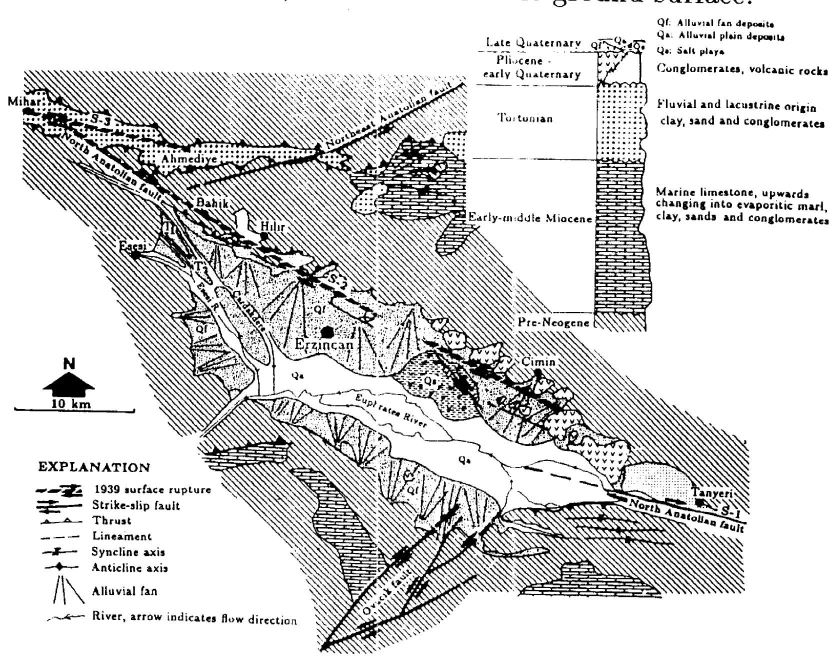

Fig. 3 Geology of the Erzincan Basin

Seismicity

Erzincan Ovası is a well known location of high seismic activity all over the world. Erzincan is located on the eastern flank of the *North Anatolian Fault* which is a well-known strike-slip fault. The earthquake occured at 19:19 on local time on March 13, 1992 near the city of Erzincan with a population of 93,000. The magnitude M_s of the earthquake was determined as 6.8. The epicenter of the earthquake was estimated to be 27 km deep (Bayülke 1993). During this earthquake a 45 km long rupture zone developed (Demirtaş and Yılmaz 1993). The scarps of the fault were not easily distinguished on site as the epicenter was very deep and the thick soil deposit over the fault diluted the movement. However, the surface en-echelon tension cracks coincided with the expected directions from the motion of the NAF (Aydan and Hamada 1992). There are SMA-type accelographs positioned at the Meteorological stations at Erzincan, Tercan and Refahiye near the epicenter. The stations are all located on sedimentary deposites. Fig. 4 shows accelographs for the directions of NS, EW and UD during the March 13 earthquake at the Meterological station of Erzincan. Among all components, the EW component (491.89 gal) was the maximum, which is probably a natural consequence of the alignement of the NAF, which has a strike N70W in Erzincan Ovası (Basin) and its motion is of strike-slip type. The UD acceleration was recorded as 249.32 gal at Erzincan and it is almost the half of the maximum acceleration of the horizontal components, which is probably a characteristic of in-land earthquakes.

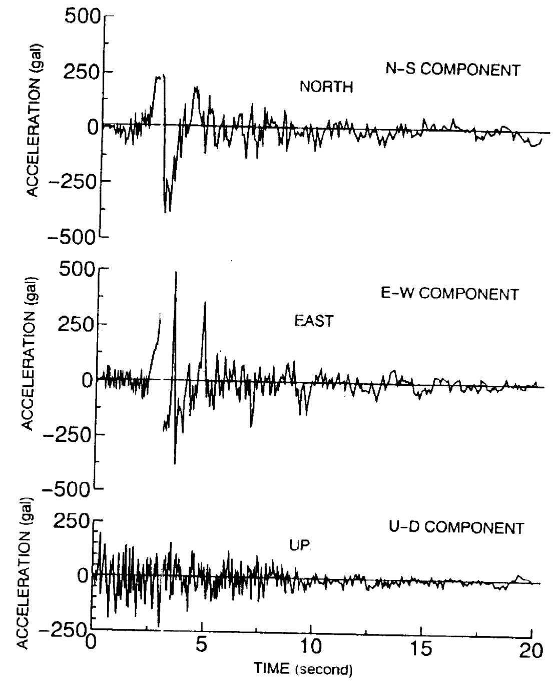

Fig. 4 Strong motion records at Erzincan

The Turkish strong motion network was established at 1973, and since then acceleration records were accumulated. The instrumental intensity evaluation of the Turkish records were carried out and compared with the records of El Centro 1940 NS and Managua 1972 EW (Hasgür 1991). Although the amplitudes of the both records were stronger than those of the Erzincan records, the Housner intesity of the Erzincan earthquake was twice that of El Centro which shows the power of strong shaking of this earthquake.

LIQUEFACTION AND LATERAL SPREADING

The old Erzincan city was located on a liquifiable ground and it was completely destroyed by the great earthquake of 1939 (M 8.0). As a result, the city was moved northwardly and relocated at its present place. During in this earthquake which was the largest one since that of 1939, there was no liquefaction induced damage in the present city of Erzincan. Post-earthquake explorations showed that the ground water level was varying between 10 to 18 meters below the ground surface even in high periods of the ground water level which makes unlikely the liquefaction of the top silty sand layer (Öztaş 1993). However, it seems that the distribution of heavily damaged structures correspondes to locations where the ground water level was relatively shallow and silty sand deposits were thick.

Severe liquefaction and liquefaction induced lateral spreading of ground were observed at Ekşisu, Karasu, Mertekli and Altınbaşak. (Photos 1-4). These localities are the old marshlands which were dried through an extensive network of drainage canals in the basin. Figs. 5 and 6 show particle size distribution curves of liquified ground at various locations and their porosities vs. unit weights. The samples were collected from sand volcanoes. In-situ explorations at Ekşisu showed that the top 4 m soil layer was silty sand or sandy silt with an SPT value ranging between 2-7 and with shear velocity V_s of 80-156 m/s. The ground water level is 0.5-2m below the ground surface which makes the ground to be susceptible to liquefaction (Erken et al. 1995).

The liquefaction induced lateral spreading of ground were observed at all localities (Aydan & Hamada 1992). Photo 4 shows a liquefaction induced lateral spreading of ground at a locality called Karasu (Aydan 1995). The ground was relatively flat (1-2%) and the site was an old bed of Fırat (Euphrates) River. Fortunately, there was no structure of importance in these sites except the regulator at Mertekli.

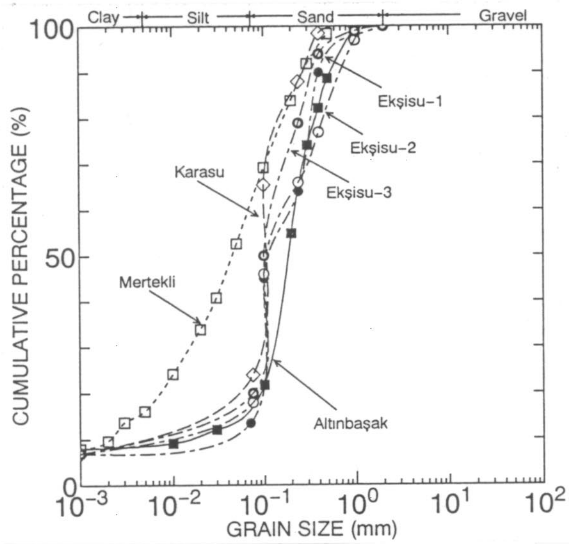

Fig. 5 Grain size distributions of liquified soil samples

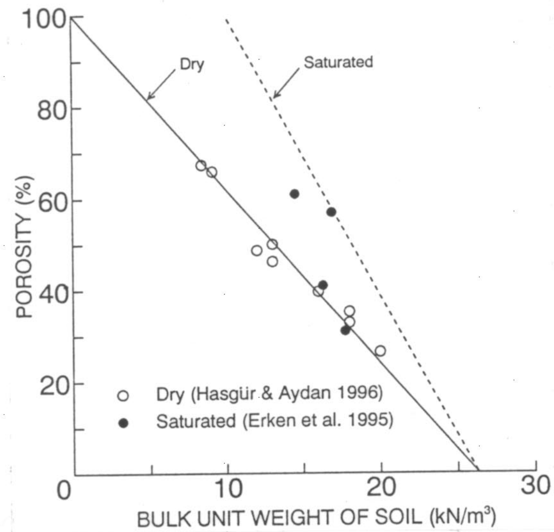

Fig. 6 Porosity of liquified soil samples

Photo 1 Liquefaction at Ekşisu

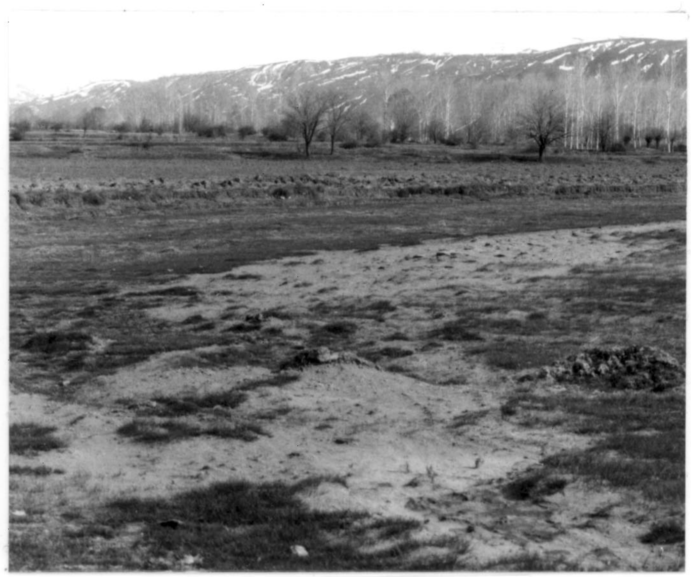

Photo 2 Liquefaction at Karasu

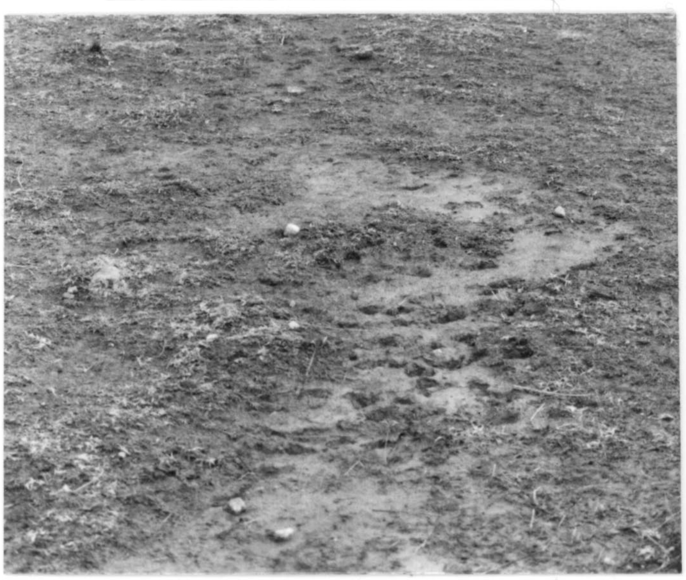

Photo 3 Liquefaction at Altınbaşak

Photo 4 Lateral spreading at Karasu

SLOPE FAILURES

Failures of natural slopes and slope cuts were observed mainly on the northern side of the basin and the northern bank of Fırat River near Tanyeri where it enters the basin (see Fig. 1 for location). However, both soil or rock slope failures were of limited scale and did not have any major impact on roadways or railways or damage on villages located next to mountain sides.

Soil Slope Failures

There were some natural soil slope failures on the banks of Fırat River (Photos 5-6). The soil is a residual type resulting from the weathering of ultra-mafic rocks. Soil slope failures were observed on the south-east looking northern bank of the river. On the opposite bank no soil slope failure was observed. The failure surface of the soil slope failures seems to be curved and shallow seated. The slope failure probably occurred on the inteface between the top residual soil and rock formation beneath.

Rock Slope Failures and Rock Falls

At several locations on the south-east looking northern slope of the narrow valley near Tanyeri, where the rock mass shows up and is highly fractured, there were also some rock slope failures (Photo 7). In addition to these, there were some rock falls weighting about 2-3 tonf at maximum (Photo 8). Some rock falls were also observed at rock cuts of roadways (Hamada and Aydan 1992, Çetinkaya 1993).

Photo 5 Soil slope failure near Tanyeri

Photo 6 Soil slope failure near Tanyeri

Photo 7 Rock slope failure near Tanyeri

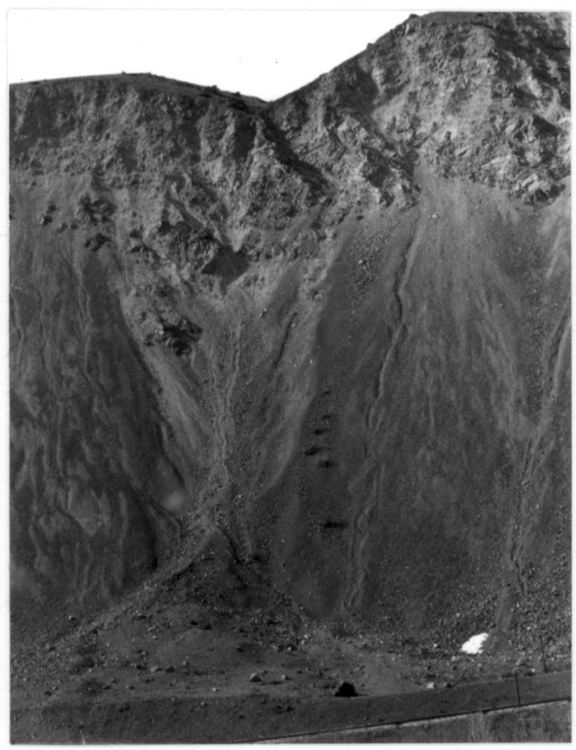

Photo 8 Rock block falls near Tanyeri

EMBANKMENTS

Failures of embankments of roadways, railways, bridges and canals were observed at numerous locations. The embankment failures were similar to soil slope failures having a curved failure surfaces and scarps of failures were observable.

Embankments of Roadways

Damages to roadways and railways were observed on various localities (Çetinkaya 1993). The localities of embankment failures of highways are as follows:

1) Erzincan - Erzurum Highway (21+000 - 31+000 kms),
2) Old Erzincan - Erzurum Highway (Ekşisu),
3) Erzincan-Refahiye Highway (13+000 - 22+000 kms),
4) Erzincan - Refahiye Highway Junction - Kelkit Highway (1+200 - 5+600 kms)
5) Erzincan - Erzurum Highway Junction - Çağlayan Highway (Regulator)

The most severe damage to the Erzincan - Erzurum Highway was observed at a locality called *Karasu*. There were lateral and longitudinal cracks on roadways, which generally run parallel to the northern side of the basin (see Fig. 1 for location). The highway was displayed by 200 mm towards the Fırat river (Euphrates) and settled by approximately 100 mm (Photo 9). This place is thought to be close to the junction point of NAF and Ovacık fault (OF) (Koçyiğit 1992, Barka and Gülen (1987)). There were also liquefaction induced lateral spreading of ground in this locality as discussed in the previous section. This type of embankment failures were also common at other highways which run parallel to the northern side of the basin.

The most severe failures of embakments occurred on highways or roads running in the direction of North-South (between Erzincan - Refahiye Highway junction and Kelkit Highway, and Erzincan - Erzurum Highway junction and Çağlayan Highway). The embankment failure of Çağlayan roadway near the Mertekli Regulator failure was the most severe one and the south-east looking part of the embankment was completely failed and settled more than 1 m. The direction of failure was consistent with the direction of maximum particle motion.

Embankments of Bridges

The most severe damage to bridges and their embankments was observed at a bridge which is a cross-over bridge on the Erzincan - Kemah Highway over the railway line. The walls of the eastern embankment of the bridge was ruptured and moved westwardly and struck the adjacent piers (Photo 10). As a result, the piers cracked at the top by bending. Piers in the middle of the bridge were also fractured by bending.

Photo 9 Displaced highway near Karasu

Photo 11 shows the failure of an embankment of a bridge over an irrigation canal. The direction of the bridge is North-South and the embankment failed by horizontal translation in the direction of East-West. Near the same bridge, a concrete conduit (1 m in diamater) under the bridge embankment was also translated in EW direction for about 10 cm which resulted in the washing-out of the soil above and the opening of a hole in the embankment (Photo 11).

Photo 12 shows the failure of the western embankment of a creek called *Karasu Çayı* under a bridge on the Erzincan - Erzurum Highway. It was also interesting that the western embankment failed by slumping while there was no indication of any failure on its eastern embankment.

Foundations and Dams

No foundation failure of buildings was reported in Erzincan or in nearby cities or towns of the earthquake-stricken area, except those of buildings adjacent to excavation pits for the foundations of buildings to be constructed.

Some settlement of the piers was observed at a bridge over *Karasu* Çayı mentioned in the previous sub-section (Photo 12). The piers were slightly inclined towards the south by approximately 3° and there was slight spalling at the connections between beams and girders.

The nearest dam to the earthquake epicenter was 60 km far. The dam was a rock-fill dam and no-damage at this dam was reported.

Photo 10 Fractured embankment walls of a cross-over bridge

Photo 11 Embankment failure of a small bridge

Photo 12 Embankment failure of a bridge over Karasu Çayı

CONCLUSIONS

Liquefaction and liquefaction induced lateral spreading of ground, failures of soil and rock slopes and of embankments of roadways, canals and roadways occured as a result of the earthquake of March 13, 1992 in the Erzincan basin are presented. The liquefaction and liquefaction induced lateral spreading of ground in Ekşisu, Altınbaşak, Karasu and Mertekli, which are the sites of old marshlands did not resulted any damage since there was no structures of importance in those localities, which are always susceptible to liquefaction. This fact emphasizes the geological history of ground in siting structures and city development. Although the failure of natural slopes during earthquakes could not be prevented, it would be desirable tc identify such locations in view of siting of structures and constructing roadways and railways. The failure of embankments during earthquakes may be also difficult to prevent. However, a good design and understanding ground conditions may result in reducing the extent of structural damage.

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